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A Framework for Healthcare Information Systems: Exploring a Large System of Systems Using System Dynamics

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ABSTRACT

Government and private health agencies are being compelled by internal and external forces to integrate their electronic records and resources. Many medical systems consist of isolated, disparate implementations that are now being required to interoperate with other systems. This study reviewed the literature on healthcare and other large systems of systems (SOS) implementations and frameworks to determine common problem themes. Reports on large government systems revealed that planning frameworks had difficulty accounting for unexpected aspects of system behavior when a systems' whole exceeds the sum of its parts. System Dynamics modeling, first developed at MIT, was examined as a possible answer to comprehending large system behaviors without being overcome by implementation details.

Key words: Healthcare Information Systems, Systems of Systems, System Dynamics.

INTRODUCTION

Increasingly, physicians and health monitoring organizations are calling for interconnected and even globally available patient information systems. While some see the web as the possible foundation for clinical practice Electronic Medical Records (EMRs) held together by standards such as HTML and Health Level 7 (HL7) (McDonald, Overhage, Dexter, Blevins, Meeks-Johnson, Suico, Tucker, Schadow, 1998), fully integrated systems have proved elusive. The complexity of a single clinical level system is compounded by attempts to integrate and interconnect legacy systems as part of large-scale health initiatives. The end result would be complex Systems of Systems (SOS).

Many factors are driving an increased need for interoperability in medical information systems. Problems include: the growing cost of storing paper based records as required by law and double entry required at interfaces between electronic medical equipment and paper records (Khoumbati, Themistocleous, Irani, 2004). Legal requirements for patient accessibility and portability of medical records have been addressed in the Health Information Portability Act (HIPAA). With little in the way of architectural guidance, systems developers are breaking new ground to design these systems. It may be necessary to re-examine the core process of architecture development in order to capture the diversity and evolutionary aspects of these systems.

A literature review was used to develop a meta-analysis to identify key problem concepts in large health records architectures. The review was conducted with articles on EMRs and Systems of Systems Architectures. Due to a lack of public information on large EMR architecture implementations, publicly available reports on US Government systems integration progress were included because they illustrated SOS development issues. An examination of these projects revealed massive failures in implementation as well as multi billion dollar losses in these systems. These failures lead to the drafting of the Clinger-Cohen Act (CCA) in 1996 as a means of enforcing accountability in government IT projects. As well as requiring accountability in IT spending, the act mandates results-based management and the establishment of CIOs with defined duties and responsibilities (Liu and Hwang, 2003).

CURRENT STUDY METHODOLOGY

The literature was reviewed to identify common issues which were then flagged and tabulated to discern possible issues and patterns. A sample group of 27 articles comprised the basis of the initial concept development. The articles were chosen by titles that indicated they focused on healthcare systems and large systems of systems. These articles were read in-depth and formed the basis for the keyword list. Keywords were chosen based on their relevance to healthcare systems and large systems of systems. In order to be chosen, a keyword was used by an author as a prominent systems concept within the article as opposed to being mentioned in passing.

Keywords were also studied for discernible patterns of development problems in large US government information systems. Frequency keyword counts were based on number of prominent keyword occurrences literally in the text as well as their use as synonyms for related concepts. The resulting list formed the basis for a more extended literature review totaling 113 articles using essentially the same procedure. Scanning was not automatic; qualitative judgments were made. For example, repeated uses of keywords were chosen on the basis of either their elaboration of a concept or their juxtaposition with other keywords rather than simply their reappearance within other articles.

The keyword totals were assembled in an Excel spreadsheet that appears in Appendix 1. The keywords were assembled into a relationship chart (Appendix 2), to discern possible conceptual relationships. Examples of frequently mentioned system needs (appearing as hubs in the diagram) were: "Interoperability, "systems architectures", "Systems communication". Examples of frequently mentioned systems factors keywords included: "Standardization", "Leadership", "Coercion/Political" and "Decentralized Architecture". The number of links between charted items appears in the fourth column in Appendix 1.

Preliminary Analysis

The keyword analysis appeared to support the view that interoperability, collaborative systems, communications, standardization and architectures were prominent concerns of healthcare and large systems architectures. Structured systems issues such as these are expected as part of an engineering approach. Interestingly, discussions of large information systems development also pointed to the importance of human factors with keywords such as political/coercive power and leadership as important drivers and inhibitors to systems architecture development. These keywords were sometimes found within discussions of factors concerning resistance to change. For example, the US government General Accounting Office (GAO) reports on data interchange projects cited leadership problems as prominent factors impeding the progress (GAO-04-40). Non-mechanical terms such as human factors, leadership, and stakeholders appeared as hubs (See Appendix 1).

The keyword diagram indicated specific healthcare information systems and concepts such as VistA, CHCS and the HealthEVet initiative were discussed in terms of their definitions rather than their relationships to systems architectures. For example HeatlhEVet was described in relation to "healthcare patchwork", its stakeholders and its regulators (HIPAA). It is not as directly linked to interoperability, architectures or "Collaborative System-of-Systems". This suggests that there is more of a gap in the literature regarding the proposed macro level architectures to bind and develop these systems. This led to a closer examination of available articles specifically describing large systems architectures in an attempt to discern what levels and types of planning are currently in use and what may be applicable to healthcare information systems.

Reviewing conceptual diagrams of large US government systems architectures, such as the Enterprise Architecture Management Maturity Framework (EAMMF), indicated a view of systems development/evolution as an assumed linear progression over time (GAO-04-40). A characteristic of SOS has been described as the lack of a defined end state; that is, it is a continually evolving structure (Carlock and Fenton, 2001). This implies a problem with representational modeling of an SOS – how to represent this ambiguity or to define stages if evolutionary stages are not clearly delineated. Engineering specifications for system components may not be sufficient to describe emergent properties of the system; that is, properties which are characteristics of the system as a whole, but not seen in the parts (Checkland, 1981). The actual behaviors of systems as a sum may be counterintuitive to their separate functions.

A fundamental problem with modeling any large system is that every detail of its processes and parts are not in written or schematic form. Nuances of production processes and procedures may reside in mental models that are by-products of organizational learning. Usually there is a great deal of practical production information that is held by the workers. This information may be imprecise and be difficult to capture with traditional modeling specifications (Radzicki, 2004).

Another problem with mental models is the difficulty in accounting for delays in system behavior. Real-world systems may seldom exhibit orderly, linear behavior. There may be large time intervals between developmental phases or implementation results. This gap between cause and effect can make it difficult to perceive the dynamics of a system: "The longer the delay between cause and effect, the more likely it is that a decision maker will not perceive a connection between the two" (Radzicki, 2004). Significant system behaviors may never be captured in the design due to this perceptual shortcoming. Additional ambiguity may arise from the interaction between engineering problems and human factors in a complex system. As indicated by the keyword diagram, human issues such as leadership, coercion, and parochialism may not be explicitly mentioned with great frequency; however, they may peripherally interact with architecture engineering and thus affect architecture systems.

While the reviewed architecture frameworks do incorporate organizational elements, actual outcomes are not always anticipated. This suggests a different modeling technique may be necessary to describe the real-world behavior of complex systems. The interaction of architecture planning frameworks and human factors may require a methodology that can capture more unpredictable problems in architecture planning as well unexpected behaviors of the resulting systems. A methodology that might suit this need is system dynamics, first developed by Jay Forrester at MIT. The literature review and analysis did reveal instances of system dynamics in relation to SOS problems; however, there did not appear to be a direct link between this methodology and development of large healthcare information systems (See Appendix 2).

System Dynamics

One possible way to imagine why a large system is counterintuitive is to consider what may happen in engineering projects when previously independent subsystems are connected with the goal of achieving a desired, larger system - a process Weiss and Glanville described as aggregation. Unexpected, emergent properties may also arise as the result of interactions between subsystems and their environment (Weiss and Glanville, 2002). System Dynamics allows for representation of non-obvious evolutionary patterns. The characteristics of complex systems as defined by Forrester are:

1. Systems greater than 4th order.
2. Contain multiple loops - 3 or 4 interacting feedback loops that can shift in dominance.
   A. Positive feedback loops - goal divergent, tending to depart exponentially from some point of unstable equilibrium.
   B. Negative feedback loops - goal seeking, tending to push the system to some objective.
3. Non-Linear: it allows one feedback loop to dominate the system and then dominate shifts to another part of the system with seemingly unrelated behavior.
4. Possesses characteristics that are commonly unknown (Forrester, 1970).

Project tools such as critical path methods, Gantt and Pert charts have been criticized for their sequential nature and inability to capture fluctuations in time or dynamic change. Simple proportional relationships that occur in real life are difficult to capture with linear planning methods (Sterman, 1992). The modeling of these interactions is intended to bring into focus that may appear counterintuitive under other models.

The case for investigating the use of system dynamics for healthcare systems architectures may be seen in a comparison of some of the systems interoperability reports found in the literature review. For example, the veteran's Administration (VA) and the Department of Defense (DOD) have been working on interoperability issues for veterans' healthcare records that are handled by the two agencies. Findings listed in this report as well as a study done by the Software Engineering Institute (SEI) at Carnegie Mellon University are compared in the following table to Forrester's principles of system dynamics (See Table 1):

The techniques used for conventional systems planning are not able to account for non-linear relationships. Some of the most prominent problems cited for implementation failures or lack of progress were related to human/organizational issues. Mathematical models or linear planning does not readily describe these issues. Forrester's argument that complex systems are composed of multiple positive and negative feedback loops becomes

Systems Dynamics (Forrester 1970) - systems are:	Interoperability Reports
Counterintuitive	/DOD lack of management structure inhibits technical development (Koontz, 2003). k of strategies to deal with current and future uncertainties (GAO-04-402T). nsitive Interoperability (Morris, 2004). covered perspectives orthogonal to original SOSI model - people, lifecycle (Morris, 2004). biguity - may never have precise definition of interoperability (Morris, 2004).
Insensitive to changes in many systems parameters	gram staff reluctant to relinquish control (Morris, 2004). ochialism (GAO-04-40).
Resist policy changes	renched mid-level managers resist change (Leopold and Fuller, 2001). icy decisions frequently reflect only a single domain (Morris, 20004).
Contain influential pressure points -often in unexpected places from which forces will radiate to alter system balance	:d to identify all dimensions and compatible models to address interoperability (Morris, 2004). .ding and control not aligned (Morris, 2004).
Counteract and Compensate for externally applied corrective efforts by reducing corresponding internally generated action	;acy - introduction of new technologies tends to break old technologies (Morris, 2004). ·tia and lack of progress in VA/DOD data exchange (GAO-04-40).
Often react to a policy change in the long run opposite to how they react in short run	icies drafted in a vacuum (Morris, 2004).
Tend toward low performance	int-to-to-point interoperability" - specific only to targeted systems (Morris, 2004).

Table 1: System Dynamics concept comparison with literature review concepts.

more compelling. Tightly coupled systems in which a change in a part of the process causes a ripple effect to other parts of the systems. This can make system behavior appear "counterintuitive". Self-correcting or reinforcing effects can be seen as examples of feedback (Sterman, 1992).

Forrester defines negative feedback loops as goal seeking with a tendency to regulate the system toward an objective. This behavior is most familiar to systems planners and is the natural tendency. For example, the Enterprise Architecture Management Maturity Framework (EAMMF) is based on progressive stages and cause and effect relationships. EAMMF and other Zachman inspired frameworks attempt to conceptualize fundamental questions of what, how, where, who when and why in clearly defined relationships. However, a problem with these frameworks may be the high-level, sweeping generalizations used to describe the tasks. They are also static and tend to emphasize structure (Weiss and Glanville, 2002). This static representation can obscure many performance related aspects of the system.

A fundamental problem in viewing a complex system in this way may be the neglect of positive feedback loops. These loops are goal-divergent and tend to depart exponentially from some stable point of equilibrium. Forrester attributes its properties as stemming not only from structure, but also many variables surrounding the loop, which may in turn be controlled by other loops. The interplay of positive and negative loops allows one loop to dominate the system for some time until the dominance shifts to another part of the system (Forrester, 1970). This subtle interplay can obfuscate the system view when the expectation is an orderly progression over time with clearly defined cause and effect relationships. Interaction between distant event loops may be the actual cause of system behavior.

System dynamics has been said to model problems rather than the systems themselves. This level of removal from implementation details is seen as the necessary element to understand system behavior (Radzicki, 2004). In order to illustrate the concept of behavioral modeling within a framework, the EAMMF framework that was previously mentioned, will be compared with possible system dynamics modeling techniques. The original version of the EAMMF consists of 5 successive stages of development with each stage containing 4 attributes. The stages represent a linear development (maturity) progresses with time (See Figure 1).

The framework appears static and descriptive despite the implication of a progression through time. It is difficult to determine how long each phase may take and how different rates of completion may affect the project as a whole. The stages are described in generalizations, making actual implementation difficult to visualize. This gives a sense that the structure does not allow for the representation of unusual events.

	Stage 1: Creating EA awareness	Stage 2: Building the EA management foundation	Stage 3: Developing EA products	Stage 4: Completing EA products	Stage 5: Leveraging the EA to manage change
Attribute 1: Demonstrates commitment		core elements (2)	core elements (1)	core elements (1)	core elements (1)
Attribute 2: Provides capability to meet commitment		core elements (3)	core elements (1)	core elements (1)	core elements (2)
Attribute 3: Demonstrates satisfaction of commitment		core elements (3)	core elements (3)	core elements (5)	core elements (3)
Attribute 4: Verifies satisfaction of commitment		core elements (1)	core elements (1)	core elements (1)	core elements (2)

maturation →

Source: GAO.

Figure 1: EAMMF Architecture example. Source: (GAO-04-40)

These same stages could be modeled with the flow and stock methods of System Dynamics (Figure 2):

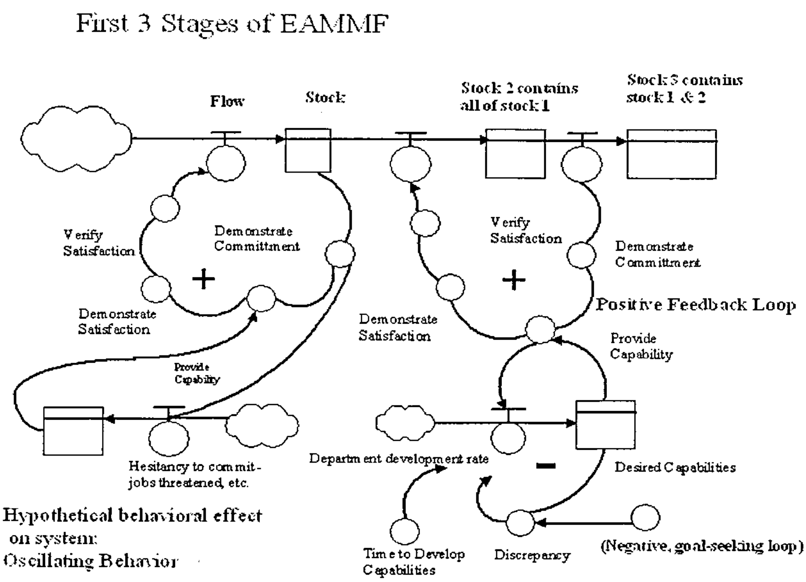

Figure 2: Original diagram using modeling techniques from System Dynamics Roadmaps (1996).

In this case, the model also describes some possible effects of human factors on the framework. Issues such as threat rigidity (hesitancy to commit) and change management problems (discrepancies in needed departmental capabilities) can be illustrated in this manner. This allows the modeler to anticipate problems that may manifest themselves as counterintuitive system behavior.

Implications for EMR Architectures

The interplay of changes based on medical/technological advances, societal demands and regulatory changes will drive dynamic healthcare systems development. The combinations of these factors will require an architecture development system capable of describing emergent properties of evolving systems. As suggested by the current review, there may be gaps in the literature in relating human and social factors explicitly in discussing large systems architectures. Concepts such as coercive power, leadership and political stability appear to only be peripherally discussed and may possibly contribute to counterintuitive problems in SOS planning and architecture. In order to fully understand and plan these systems, it may be necessary to describe the interactions of human decision-makers and cost allocaters as well as the technical specifications.

Systems Dynamics may be a viable methodology to meeting these needs if properly applied. There are dangers of oversimplification in applying the causal-loop methodology, which has been a popular method for learning these concepts. This may lead to logical fallacies in the system conceptualization (Richardson, 1986). This problem notwithstanding, the need for a means of conceptualizing complex systems which contain social aspects as well as their own emergent properties appears to lie outside the realm of completely goal-directed modeling frameworks.

There has been some work on applying System Dynamics modeling to the delivery of health and social care systems. In the U.K., this work has cited a conflict between the managerialist approach and the more reflective style of System Dynamics (Wolstenholme, Monk, Smith, & McKelvie, 2004). Another work on Evidence Based Care Systems described managerial decision making as a narrow range of policy options ranging from pre-conceived ideas and linear thinking to doubts about policy implementation due to organizational culture (Deakins, 2001). This suggests the application of a modeling methodology that has the advantages of 'soft' and 'hard' operations research (OR).

SUGGESTIONS FOR FUTURE STUDY AND DEVELOPMENT

The new demand for EMRs fits the description of what have been called "'unprecedented systems' ... those which employ new concepts or involve a new mix of technologies or push the employment of existing concepts beyond the present limit of understanding." (Weiss and Glanville, 2002). The interplay of human factors and social systems are an inescapable part of the system development process. While Soft OR allows for the general case and the unexpected aspects of the human equation, it does not explain the system in its entirety. Similarly, Hard OR provides the rigor for the specific case while being unable to account for vagueness or uncertainty. System Dynamics may be an approach to bridge this gap. The literature review revealed System Dynamics is being used in multidisciplinary fields, but does not appear to be a consideration for EMR development.

System Dynamics allows designs to be to be run as simulations that could subsequently generate empirical data on SOS performance. This data could be compared with large enterprise architectures already in place. The benefits of SOS could also be studied through empirical research based on System Dynamics modeling using survey methods. Conceivably this information could help avoid costly system development failures.

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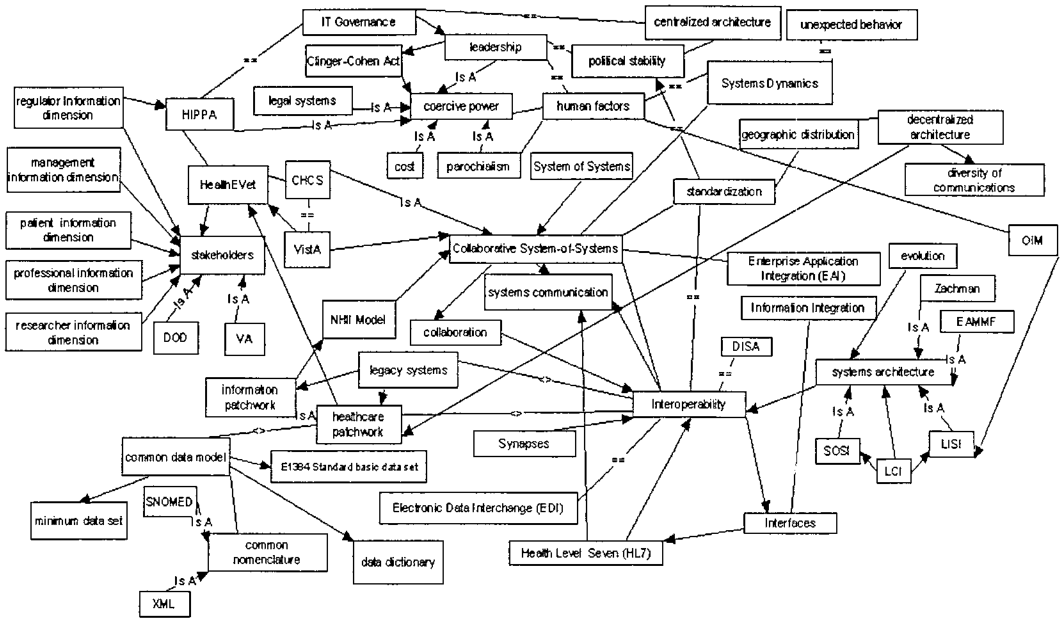
APPENDIX 1

Keyword	Frequency	Number of links to other keywords
patient information dimension	10	1
Patient Mobility	3	0
Patient Record Institute (CPRI)	1	0
patient safety	8	0
point-to-point interoperability	1	0
Political stability	21	2
professional information dimension	12	1
project management structure	4	0
qualitative	1	0
rate-to-level	2	0
rational systems	3	0
Reference Information Model (RIM)	3	0
regulator information dimension	4	2
reliability	3	0
Research Systems	1	0
researcher information dimension	4	1
results-based management	1	0
security	1	0
SNOMED	4	1
social systems	6	0
soft operations research	6	0
SOSI	3	2
stable intermediate forms	4	0
stakeholders	7	8
standardization	45	4
Synapses	1	1
Synergy Extranet (SynEx)	1	0
system boundaries	1	0
System Scope	3	0
Systems Architecture	33	9
systems communication	54	3
Systems Dynamics	16	3
Systems of Systems	12	1
SystemsDynamicsModeling	3	0
Technical architecture	9	0
Transitive interoperability	2	0
Two-way data transfer	6	0
UHDDS	1	0
unexpected behavior	9	1
uniform data sets	3	0
VA	3	1
virtual	7	0
VistA	2	3
Web-based clinical systems	9	0
XML	2	1
Zachman	2	1
Total Keywords	**324**	
Total Links		**45**

APPENDIX 2


IT Governance
centralized architecture
unexpected behavior
leadership
Clinger-Cohen Act
political stability
Systems Dynamics
regulator information dimension
HIPPA
legal systems
coercive power
human factors
geographic distribution
decentralized architecture
management information dimension
HealthEVet
CHCS
cost
parochialism
System of Systems
diversity of communications
standardization
patient information dimension
VistA
Collaborative System-of-Systems
OIM
stakeholders
professional information dimension
Enterprise Application Integration (EAI)
evolution
systems communication
Zachman
researcher information dimension
DOD
VA
NHII Model
collaboration
Information Integration
EAMMF
DISA
legacy systems
systems architecture
information patchwork
healthcare patchwork
Interoperability
SOSI
LISI
LCI
Synapses
common data model
E1384 Standard basic data set
SNOMED
minimum data set
Electronic Data Interchange (EDI)
Interfaces
common nomenclature
data dictionary
Health Level Seven (HL7)
XML
Is A
==
<>